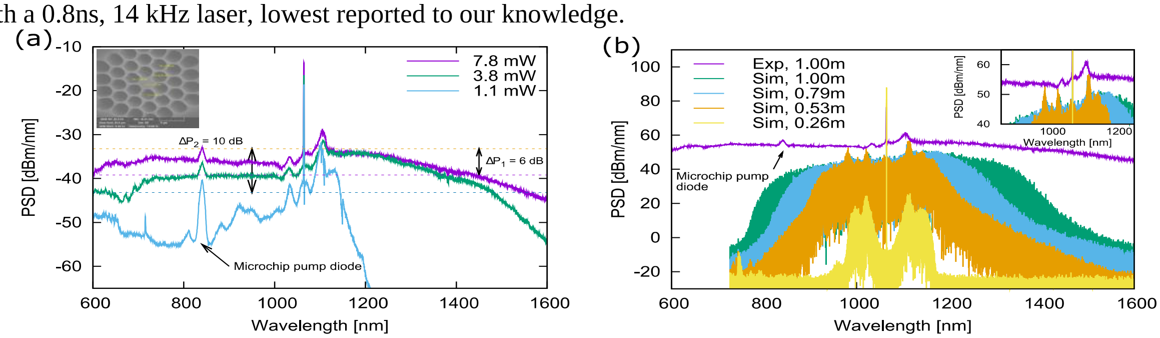
1.3 Octave Supercontinuum Generation in Highly Ge-doped Photonic Crystal Fiber

Deniz Aydin[1], Thibault North[1], Achille Monteville[2], David Landais[2] and Olivier Legoffic[2], David Méchin[2], Camille-Sophie Brès[1]
Photonic Systems Laboratory, Ecole Polytechnique Federale de Lausanne (EPFL), CH--1015 Lausanne, Switzerland
Photonics Bretagne (PERFOS), France, 11 Rue Louis de Broglie, 22300 Lannion, France
Author e-mail address: deniz.aydin@epfl.ch

Abstract: We present a flat, visible 1.3-octave supercontinuum generated in a GeO_2-doped photonic crystal fiber owing to an overlap of the modulation instability and Raman gain regions resulting in efficient energy transfer to new frequency components.
OCIS codes: (320.0320) Ultrafast optics; (320.6629) Supercontinuum generation; (060.2280) Fiber design and fabrication

Supercontinua are of interest for numerous industrial applications including sensing, imaging, and frequency comb generation as well as in optical device characterization. Recently, Q-switched lasers were found to be compelling candidates for supercontinuum generation in the long-pulse regime [1–3]. Here we present supercontinuum generation between 620 – 1552 nm in a highly doped photonic crystal fiber (PCF) pumped with a passively Q-switched sub-ns microchip laser at 1064nm. Efficient generation is enabled even at low pump powers owing to overlapping modulation instability (MI) and Raman gain regions.

We designed a hexagonal lattice, solid-core silica matrix PCF with a 20% mol. GeO_2 doped, 3μm core and strong index contrast ($\Delta n= 30\times10^{-3}$) between the core and the cladding (Fig.1a, inset) fabricated by PERFOS. The PCF has $n_2 = 4.709 \times 10^{-20}$ m^2/W and a Raman gain of $g_R = 7.07\times10^{-14}$ m/W. We measured the zero dispersion wavelengths to be λ_{ZDW}=1047 nm and 1050 nm for the two principal polarization axes. Dispersion is 6.44 ps/km-nm at 1064nm, the attenuation 0.17dB/m and γ=50 $(W\text{-}km)^{-1}$. In Fig.1a the supercontinuum is generated after 1m of fiber for various input powers: a flatness of <6 dB over 820 nm extending from 620 nm to 1440 nm (Fig. 1a), and <15 dB over 932 nm between 620 nm - 1552 nm is observed for P_{ave}=7.8mW (P_{peak}=670W). This result is competitive with similar sources using longer fibers (1.8 – 20 m) and higher peak powers [4–6] in the same ns pulse regime. Notably, in Fig. 1a we start seeing supercontinuum in 1m of fiber (bandwidth >250nm) at markedly low peak powers of 98W (P_{ave}=1.1mW) with a 0.8ns, 14 kHz laser, lowest reported to our knowledge.



Fig, 1: (a) Experimental supercontinuum in 1m PCF, 0.8ns pulse duration at 14 kHz; (b) Simulations showing spectrum evolution as a function of fiber length and experiment in 1m fiber for P_{ave}=7.8mW, overlaid with experimental result. Traces are offset for visibility.

The generating mechanisms of this supercontinuum are studied using the generalized nonlinear Schrodinger Equation (GNLSE) solver [7], modified to include measured attenuation and quantum noise. Simulation results (Fig. 1b) show an evolution starting from MI. Raman response of GeO_2 reaches its maximum at 13.2THz extending from 10-15THz. Accordingly, MI and Raman peaks overlap, producing a highly efficient energy transfer from pump to shorter and longer wavelengths. This effect is primarily responsible for the extremely wideband spectrum competitive with current research-grade and commercial sources operating in the nanosecond pulse regime.

1. W. J. Wadsworth, et al., "Supercontinuum and four-wave mixing with Q-switched pulses in endlessly single-mode photonic crystal fibres," Opt. Express **12**, 299–309 (2004).
2. J. M. Stone and J. C. Knight, "Visibly ``white'' light generation in uniform photonic crystal fiber using a microchip laser," Opt. Express **16**, 2670–2675 (2008).
3. A. Mussot, et al., "20 THz-bandwidth continuous-wave fiber optical parametric amplifier operating at 1um using a dispersion-stabilized photonic crystal fiber," Opt. Express **20**, 28906–28911 (2012).
4. S. Coen, et al.l, "White-light supercontinuum generation with 60-ps pump pulses in a photonic crystal fiber," Opt. Lett. **26**, 1356–1358 (2001).
5. NKT Photonics, *NKT Supercontinuum Application Note V2.0 July 2009* (2009).
6. C. Xiong, et al., "Enhanced visible continuum generation from a microchip 1064nm laser," Opt. Express **14**, 6188–6193 (2006).
7. J. M. Dudley and S. Coen, "Supercontinuum generation in photonic crystal fiber," Rev. Mod. Phys. **78**, 1135–1184 (2006).